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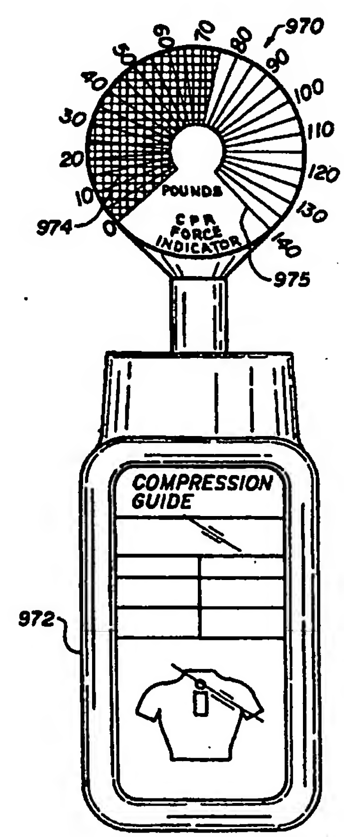
(57) Abstract

A force sensing system for a CPR device which generates an intelligible output signal corresponding to a force parameter. The sytem is comprised of a sensing device for sensing force exerted thereon and producing an electric reactance signal in response to the force exerted, and a processor for processing the electric reactance signal into an intelligible output signal which is shown on a display device (974).



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SENSOR AND TRANSDUCER APPARATUS

This application is a continuation-in-part of application Serial No. 07/621,653 filed on December 3, 1990, for a "Sensor and Transducer Apparatus" by Nicholas F. D'Antonio and Nicholas J. D'Antonio, which is a continuation-in-part application Serial No. 06/834,939 filed on February 28, 1986, and of Serial No. 07/151,483 filed February 2, 1988.

BACKGROUND OF THE INVENTION

1. THE FIELD OF INVENTION

This invention relates generally to systems for sensing environmental or physical parameters such as for pressure, temperature and light changes, and to transducers for generating electrical signals corresponding to such remotely sensed environmental or physical parameters. The invention further relates to an electronically operated CPR force monitoring system.

2. STATE OF THE ART

A great many devices are known for sensing force and pressure values. For the purposes of the present discussion, the terms force and pressure can be considered interchangeable, and to include other force related values such as torque. Likewise, devices are known for sensing temperature and light parameter changes. Many of such devices are mechanical in nature, and many are electrical devices. While many of these devices have proven very effective for their intended uses, there remains a need in many areas for compact, reliable, effective, inexpensive and low power sensor and transducer devices and systems. For example, in U.S. Patent 4,858,620, filed on February 28, 1986 and which issued on August 22, 1989, entitled "Warning Systems for Excessive Orthopedic Pressures", a non-invasive system for remotely monitoring the pressure beneath the cast on a part of the body is disclosed for warning when the measured pressure is approaching dangerous levels. That system should incorporate remote sensors which are compact enough to fit beneath the cast without requiring any modification to the cast's size or shape. Furthermore, the system, being battery operated and portable, must be reliable and effective to protect the patient, and still be of low power requirements and inexpensive. Although means are known for measuring pressures beneath casts, among the reasons why such means are not

widely used are that they are invasive, difficult to use and their prohibitively expensive, particularly in view of the present absence of such systems in existing orthopedic procedures and because the addition of such systems would significantly increase the cost of the cast. Another medical application requiring a force detection system is a CPR unit in which the force applied to the lower sternum is displayed in real time for each of the cyclic compressions during the procedure. The object, of course, is to prevent forces that are too low to be effective or so high as to cause physical damage to the patient's chest.

Aside from the medical application discussed above, there are other applications where a need exists for low cost, remotely located sensors to be utilized in transducer circuitry. For example, such need exists in the automotive industry. This need is discussed by Flynn, in his article in Product Engineering, August, 1978 (pgs. 43-49).

A number of electrical devices have been developed and described in the patent literature for detecting changes in environmental or physical parameters. One such device is described in U.S. Patent 4,552,028. This patent discloses a single device for measuring force by a capacitive sensor.

U.S. Patent 4,562,382 discloses a solid-state inverter including a multiple core transformer which is useful as a high frequency power source for use in connection with an electron discharge lamp.

In U.S. Patent 4,381,506, a single unit transducer apparatus is disclosed. This apparatus provides an electrical signal which senses motion of a component, e.g., a movable ring about a magnetically conductive core. This apparatus is designed for coupling to internal combustion engines.

In U.S. Patent 4,156,223, an improved positional transducer is disclosed which utilizes an elongated, hollow, cylindrical tube of a magnetically saturable material, a sensing wire that runs through the tube parallel to its elongated axis and a pair of elongated, generally rectangularly shaped magnets of opposite polarity which are closely positioned adjacent diametrically opposite exterior portions of the tube. A similar positional transducer is illustrated in U.S. Patent 3,958,203; however, the '223 patent is an improved version of the transducer disclosed in this patent.

U.S. Patent 4,122,427 discloses a motion monitor particularly useful for monitoring infant respiration. The monitor comprises an oscillator driving an ultrasonic wave generator, a receiver for ultrasonic echoes, a phase detector for detecting phase shift between the outputs of the detector and an oscillator, and means for recovering the respiration envelope from the output of the phase detector.

U.S. Patent 3,140,475 discloses a device for position and motion indication. The device includes a primary coil and a secondary coil coaxially aligned in an end-to-end relation and electrically connected in series, with an A.C. supply connected across the primary coil and a signal readout device connected across both the primary and secondary coils in series relation.

In U.S. Patent 3,020,527, a position indicating system which will indicate the position of a device at a location remote from a movable device is provided. More specifically, a telemetric system is disclosed that may be employed expeditiously with an elongated tube which tube may act as a pressure wall.

U.S. Patent 3,001,183 also relates to position indicator systems for sliding magnetic sleeves which operate within a completely enclosed vessel. Specifically, a remote linear position indicator is disclosed that has a sensing element positioned within a tubular magnetic wall.

U.S. Patent 2,284,364 discloses a tensiometer for measuring thread tension while the thread is passing through the measuring device at a high rate. This device was designed for use in the fiber and garment industries.

U.S. Patent 3,142,981 discloses a transducer device for producing digital electrical signals to measure the magnitude of force applied to the force sensing element. The force sensing element includes a load ring, and a means for applying a force to cause a deformation of the load ring. The patent also discloses employing an oscillator to produce a stable frequency within the frequency range of the oscillator whose frequency varies with the force applied to the load ring.

U.S. Patent 3,206,971 discloses a force measuring apparatus wherein a frequency determining part of an oscillator is coupled to a spring member. The resilient deformation of the spring member caused by the forces to be measured produces frequency changes in the oscillator corresponding in magnitude to the

deformation.

U.S. Patent 3,522,858 discloses a snow-depth measuring device which permits measurement of small changes in the pressure of a liquid contained in a factory sealed chamber between two parallel plates, one of which is exposed to the snow fall. Attached to the outer frame of the device is a pressure transducer comprising bellows, a core piece and a coil, all enclosed in a housing.

U.S. Patent 3,727,606 discloses a device for providing continuous monitoring of human respiration and heart rate comprising a fluid-type mattress located in contact with the human and producing pressure signals in response to the breathing and heart rate. A pressure transducer is provided for interpreting the pressure signals for application to an electronic circuit, or visual or audible recognition of the signals.

U.S. Patent 3,791,375 discloses a device for sensing and warning of excessive ambulation force. The device is designed to be worn on a human foot, and may be used during recovery from orthopedic surgery of the lower extremity. The device comprises a fluid-containing load cell which deflects and changes its volume in accordance with the amount of load thereon.

U.S. Patent 4,175,263 discloses a technique for monitoring the movement of an individual from a particular area. The device comprises a sealed fluid filled pad and comprises two distinct fluid areas or pressure sensing areas. Movement of a patient or a child is detected by the change in force or pressure exerted on the fluid.

U.S. Patent 4,208,918 discloses a digital pressure sensor in which a first oscillator is associated with the pressure detector and a second oscillator of the same construction as the first is provided for determining a sampling period of the output signal of the first oscillator.

U.S. Patent 4,324,259 discloses a device for detecting body function changes such as respiration and contractions of a woman in advanced pregnancy and labor. The device comprises a detector capsule having one wall defined by a resilient diaphragm for engagement with the abdominal wall and is connected to a variable volume compartment operably connected to a volume responsive transducer.

German Patent 737,882 discloses a position indicator which includes a

movable magnetic sleeve about a core element containing longitudinal windings to vary inductance.

None of these above disclosures, however, teach or suggest the sensing means of the present invention. Also, a remotely located sensor from the transducing means of the type disclosed in the present application is not suggested by the teachings of the above discussed disclosures.

Other applications for pressure and the like monitoring systems, which might well be fulfilled upon the availability of compact, reliable, effective low power, portable and inexpensive remote sensors and associated transducer functions, involve measuring sport related values (e.g., measuring force applied to boxing gloves, boxing bags and running shoes; measuring total energy expended in bicycling; monitoring pressure in ski bindings and ski boots; measuring muscular expansion in a weight lifter); measuring the redistribution of body fluids in space or when subjected to varying and/or extreme gravitational forces; measuring weight; measuring pneumatic tire pressure, etc. Also, such a monitoring system may be useful for the remote monitoring of pressurized containers, e.g., fire extinguishers and gas containers used with analytical instruments and the like, respiration therapy, automotive performance, and monitoring fluid flow and fluid levels in industrial processes, to name a few.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an inexpensive pressure sensor.

Another object is to provide a pressure, temperature and/or light sensor which is compact.

A further object is to provide a pressure, temperature and/or light sensor, which is reliable and durable.

The provision of sensing systems for sensing environmental or physical parameters and for providing signals reflective of the value of those parameters at remote locations, is another object of the invention.

Another object is to provide a sensing system for generating an intelligible output signal corresponding to an environmental or physical parameters at a location remote from the place where the parameters is sensed.

Still another object is the provision of a compact, inexpensive, low power and accurate sensing means for generating electric signals for transmission to a remote processor.

Another object of the present invention is to provide a sensor and transducer system which can be used to measure and display forces such as the force applied to the sternum during the CPR procedure. The technique is applicable to portable devices for use in emergency situations removed from a clinical setting or for use with more stationary equipment in hospitals or trauma centers.

Another object of the present invention is to provide a sensor and transducer system that is applicable to a wide variety of uses, while being inexpensive, reliable, compact, durable and low power.

Other objects will be apparent from the description to follow and from the appended claims.

The foregoing objects are achieved according to preferred embodiments of the invention by the provision of a sensing system for generating output signals according to the value of a sensed environmental or physical parameter, the system having sensing means composed of relatively movable electrical members which generate electric reactance signals corresponding to the value of the environmental or physical parameter. The reactance signal is transmitted to a processor having a CMOS Schmitt trigger logic inverter oscillator which receives the signal and generates a corresponding transduced signal for further processing to yield the output signal. The sensing device is preferably composed of an inductor coil mounted on a supporting member, and a second inductor element movable relative to the coil for generating an inductance signal corresponding to the value of the sensed parameter. The sensing device can alternatively be composed entirely of resistive or capacitive elements whose output is reflected by a reactance response in the oscillator, wherefore, the output of the sensing device is broadly described as a reactance signal. Various specific structures of the foregoing components are provided according to the application to which the inventive concepts are employed.

According to the preferred embodiments described below, a CPR

compressive force monitoring system includes a section for being placed on the sternum of a victim. Compressive manual force is applied to the section. The force is monitored so that it can be held within safe and effective values. The monitor or force sensing system has a stationary position and a movable portion for generating an electrical reactance signal according to the applied force. A force dependent oscillator generates a signal whose frequency corresponds to the force, and a frequency-to-voltage converter generates a voltage signal corresponding to the applied force. Comparators receive the voltage signal and generate a comparator outlet signal corresponding to the magnitude and change of the applied force. An electronic (such as an LCD) or mechanical display reveals an intelligible output signal on indicators showing force values.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a schematic diagram of a sensor system according to a preferred embodiment of the invention for indicating the sum of a number of sensed pressures and illustrating a reluctance type remote sensor.

FIGURE 2 is a schematic diagram of a sensor system according to a preferred embodiment of the invention for indicating the maximum value of a number of sensed pressures and illustrating a resistive type remote sensor.

FIGURE 3 is a schematic diagram of a sensor system according to a preferred embodiment of the invention for indicating the cumulative or average value of a number of sensed pressures and illustrating a capacitive type remote sensor.

FIGURE 4 is a perspective view of a sensor pad according to one embodiment of the invention.

FIGURE 5 is a circuit diagram of signal processing circuitry pursuant to an embodiment of the invention which incorporates a CMOS Schmitt trigger logic inverter transducing oscillator for an inductive, resistive or capacitive (i.e., a reactance) sensing signal from a remotely located sensing device.

FIGURE 5A expands the processor of FIGURE 5 to include multiplexing means for multiple inputs from remotely located reactance sensors.

FIGURE 6 is a timing diagram for the circuitry of FIGURE 5.

FIGURE 7 shows a cross-section of a sensor according to another

embodiment of the invention wherein electrical characteristics are varied in accordance with sensed pressure.

FIGURE 8 is a circuit diagram of a transducing oscillator according to the invention, for generating signals corresponding to the sum or to the average value of pressure applied to remote sensors of the invention, where the resistance or the inductance is variable.

FIGURE 9 is a circuit diagram for an oscillator of the type shown in FIGURE 8, but where the capacitance is variable.

FIGURES 10(A) and 10(B) are, respectively, a cross-section and a detailed partial perspective view of a sensor pad or sensing device according to another embodiment of the invention.

FIGURE 11 is a cross-section and a detailed partial perspective view of another embodiment of the sensor pad illustrated in FIGURE 10.

FIGURE 12 illustrates a remote sensor according to the invention used in combination with a fire extinguisher.

FIGURE 13(A) is a schematic view of a sensing system according to the invention for controlling the operation of an air bag in a motor vehicle.

FIGURES 13(B) and 13(C) are perspective views of variations of an embodiment of a sensing device according to the invention for generating an inductance signal corresponding to a sensed acceleration.

FIGURES 13(D) and 13(E) are schematic views of another acceleration sensing means according to the invention, wherein a mass attached to a pendulum moves part of a sensing device to generate a reactance signal; the views show the embodiment in rest and accelerating conditions.

FIGURE 13(F) shows a variation on the preceding embodiment where the pendulum carries a permanent magnet.

FIGURE 14(A) illustrates an embodiment of the present invention used in combination with a respiratory spirometer. FIGURES 14(B)-(D) are detailed partial cross-sectional views of embodiments of the apparatus shown in FIGURE 14(A), and FIGURE 14(E) is a perspective view of an air flow intercepting flexible diaphragm.

FIGURE 15 illustrates a cross-section of a sensing device which can be

incorporated in embodiments of the invention, such as in the remote sensors of FIGURES 1, 2, 3, 10, 11, 12, 13 or 14.

FIGURE 16 illustrates a cross-section of another type of sensing device which can be used in embodiments of the present invention, such as the embodiments of the remote sensor of FIGURES 1, 2, 3, 10, 11, 12, 13 or 14.

FIGURE 17A illustrates a hand-held CPR unit with an electrically operated mechanical gauge.

FIGURE 17B illustrates an electronic version of the CPR device depicted in FIGURE 17A, wherein the display is a radial LCD wherein the shaded portion illustrates an applied force of 75 pounds.

FIGURE 18 is a schematic diagram of a preferred embodiment of the circuitry and processing elements used to generate the real time display of applied force to the CPR device depicted in FIGURES 17A and 17B.

FIGURE 19 is a graph of voltage versus force, for part of the circuitry shown in FIGURE 18.

FIGURE 20 is a perspective view of a neonatal device according to the invention.

The invention will be further described in connection with the attached drawing figures showing preferred embodiments of the invention including specific parts and arrangements of parts. It is intended that the drawings included as a part of this specification be illustrative of preferred embodiments of the invention and should in no way be considered as a limitation on the scope of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring first to FIGURE 1, a sensor system 1 is shown composed of a number of compressible pads 3, 5 and 7 connected respectively by conduits 9, 11 and 13 to a fluid container 15. Although only three pads are shown, any number N of pads can be used. The pads and their respective conduits are filled with a fluid F_1, which can be a gas such as air, but for most applications is preferably an incompressible liquid. However, the fluid is preferably a gas if a change in temperature is to be measured, for example, in a temperature controlled heated glove, boots, face mask or other wearing apparel or other apparatus or regions, such as the temperature build up trapped beneath the surface of a newly applied

cast, which if undetected, can cause further injury and pain to the patient. The pads 3, 5 and 7 enter reservoir 15 through ports 17, 19 and 21 respectively. A diaphragm 23 extends over port 17 to isolate the volume of pad 3 and conduit 9 from container 15. Diaphragms 25 and 27 similarly seal off pad 5 and conduit 11, and pad 7 and conduit 13, respectively. Fluid F_1 thus fills each pad, its connecting conduit, and the region within the diaphragm associated with the respective conduits. A port 29 is provided in reservoir 15, and a transducer diaphragm 31 extends over port 29, the latter diaphragm being disposed in a casing 33. A displaceable deflection transfer means in the form of a second fluid F_2, which fills the volume between diaphragms 23, 25, 27 and 31 (i.e., essentially filling reservoir 15), controls the flexing of diaphragm 31. Fluid F_2 may be the same as, or different from, fluid F_1. A tubular ferromagnetic shield or cap 40 is attached to diaphragm 31, for movement over an inductor coil 41 in a telescoping manner. The output of transducer diaphragm 31, providing an inductive change in coil 41 as shield 40 moves over coil 41. The output of coil 41 is shown by the arrows a, b. Outputs a and b are connected to a circuit for changing the frequency of an oscillator circuit, as the one described below in FIGURE 5.

When pressure is exerted on any or all of pads 3, 5 and 7, as indicated by the pressure values P1, P2 and P3, fluid F_1 moves through the respective conduits 9, 11 and 13 and effects an expansion of the respective diaphragms 23, 25 and 27. When not deflected, the diaphragms are attached tightly over the respective ports 17, 19 and 21 (as shown by the solid lines) to assure an accurate and detectable response to pressures P1, P2 and/or P3. FIGURE 1 shows a situation where P1 is greater than P2, and P2 is greater than P3, wherefore the deflection of diaphragm 23 exceeds that of diaphragm 25, which exceeds that of diaphragm 27. The diaphragms in their deflected states are shown in dashed lines. The effective flow areas of conduits 9, 11 and 13 should be very narrow, to get a relatively large fluid movement and diaphragm deflection for even minute pressure changes on the pad.

The expansion of diaphragms 23, 25 and 27 exerts pressure on fluid F_2, and this in turn effects an expansion of transducer diaphragm 31 (from its solid position to its dashed line portion) according to the sum of the deflection of

diaphragms 23, 25 and 27, to yield a corresponding electrical parameter change a, b. This parameter change results from the movement of cap 40 attached to diaphragm 31 at interface 42 over coil 41. The variable impedance produced as a result of the movement of diaphragm 31 changes, in this instance, the reluctance of coil 41 to change Z_1 in FIGURE 5.

Referring at this juncture to FIGURE 15, a reluctance transducer 51 which could be used to fulfill the functions of shield 40 and coil 41 is shown. This device is described in detail in U.S. 607,654 filed May 7, 1984 (attorney's docket 8943). Transducer 51 includes a core 53 about which a coil 55 is wound. Preferably core 53 and coil 55 are rigidly mounted with respect to a flexible diaphragm 57 on which a hollow cylinder 59 is securely mounted. Core 53 is preferably made of a ferromagnetic material to increase the inductance of coil 55. Hollow cylinder 59 can be a non-ferrous metallic or ferromagnetic material whose relative position will variably alter the magnetic field around the coil, allowing for either an eddy current or altered magnetization effect. As shown in FIGURE 15, core 53 and coil 55 protrude partially into hollow cylinder 59. In response to forces applied to the diaphragm (in the horizontal direction according to the drawing of